Distribution of Inorganic Nitrogen and Phosphorus Concentrations in Stream Flow of Two Southern Piedmont Watersheds

D. H. Franklin,* J. L. Steiner, M. L. Cabrera, and E. L. Usery

ABSTRACT

Innate distributions or variability of nutrient concentrations within the fluvial system must be better understood to establish nutrient guidelines that are applicable and to discern which areas or landscape positions within the watershed are more vulnerable to nutrient losses. This work was conducted to (1) determine the system-wide spatial distribution of N and P concentrations in biweekly stream samples from two Southern Piedmont watersheds, and (2) determine the relationship between N and P concentrations in biweekly samples and watershed morphological features. From December 1998 through December 2000 samples were collected biweekly from 17 sampling sites located on Rose Creek and from 18 sampling sites located on Greenbrier Creek. The samples were analyzed for ammonium (NH_4), nitrate (NO_3), and dissolved reactive phosphorus (DRP) concentrations. We found that spatial autocorrelation of nitrate concentrations was evident and that some spatial autocorrelation of DRP concentrations was also present. We further found that the fluvial network morphological feature, drainage density, explained part of the spatial autocorrelation found for nitrate but did not for DRP. These results indicate that innate variability of nutrient concentrations within streams exists and suggest that decision makers should begin to consider location within the watershed when making nutrient management guidelines and decisions.

While it is well documented that land management practices can affect stream water quality (Daniel et al., 1995; Sharpley et al., 1992), it is less understood how watershed morphology can affect stream nutrient concentrations. An increased understanding of these effects by researchers, producers, and the community as a whole may lead to the development and implementation of acceptable practices and policies that would ensure agricultural sustainability and clean water at a regional scale.

Because many factors can affect stream nutrient concentrations (Withers et al., 2000; Gburek et al., 2000), the scientific and advisory community has not yet come to consensus on acceptable levels of N and P in edge-of-field runoff or in surface waters. In a recent review of the impact of agricultural land management on N and P losses, Heathwaite et al. (2000) suggest that transport mechanisms must be considered before nutrient losses can be controlled. They also state that N and P may move through the landscape in very diverse pathways. If mechanisms for N and P losses are different and if these differences are not considered, management practices developed for P retention may be diametrically opposed to the retention of nitrate. Part of the problem lies in the scarcity of actual measurements at the field, farm, and watershed levels (Daniel et al., 1995), and in the innate variability of N and P found in soil and surface waters.

Levine and Schindler (1989) reported concentrations of 0.01 mg P L^{-1} and 0.3 mg N L^{-1} as critical levels expected to promote noxious aquatic plant growth in lake water. Critical levels of N and P in streams, however, are not as clear. The USEPA recommends stream concentrations below 0.1 mg total P L^{-1} to prevent plant nuisances (R. Raske, personal communication, 1995; Mackenthun, 1976). More recently USEPA has released potential nutrient criteria on a ecoregion basis. The recently released nutrient criteria for rivers and streams in aggregate nutrient ecoregion IX (Southern Piedmont, Georgia) is 0.036 mg P L^{-1} and 0.692 mg N L^{-1} (USEPA, 2000). Horne and Goldman (1994) state that "soluble phosphate concentrations in unpolluted rivers are usually less than 0.01 mg PO_4–P L^{-1} and often 0.001 mg P L^{-1}." Bothwell (1989) showed that when dissolved P (DP) concentrations were above 0.03 to 0.05 mg P L^{-1}, P was not a limiting factor in periphyton growth. In a review of P concentrations in southeastern U.S. streams we found the P concentrations in streams are often above these levels (0.001–430 mg P L^{-1}; Thomas et al., 1992; Lenat and Crawford, 1994; Cooper and Gillian, 1987). While the highest levels were influenced by point sources, the moderate levels were influenced by agricultural practices and by the morphology of the watershed expressed in terms of soil texture and mineralogy.

Decision makers, (farmers, state and federal environmental agencies, as well as state and federal resource conservation agencies) are continuously having to update and upgrade nutrient management strategies to ensure a sustainable future and provide the people with

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Abbreviations: CA, contributing area; DD, drainage density; DRP, dissolved reactive phosphorus; MC, Moran's coefficient; MCca, Moran's coefficient using contributing area connectivity matrix; MCup, Moran's coefficient using upstream connectivity matrix; USEPA, United States Environmental Protection Agency; USGS, United States Geological Survey.

methods of sustaining or improving the environment. Franklin et al. (2001) found that management system (crops, hay, pasture, forest) did not influence nitrate concentrations in storm flow or runoff but they influenced base flow and that stream segments dissecting pastures were found to have the lowest and highest nitrate concentrations. The high degree of variability in nitrate concentrations found in base flow for pastures under similar management suggests that other factors besides management system plays a major role in the nitrate concentrations found in these surface waters. Nutrient concentrations vary with landscape type, position, and use (Withers et al., 2000; Gburek et al., 2000). This innate spatial variability has been described by fluvial morphologists and stream ecologists. To the fluvial geomorphologist, drainage networks or the fluvial system transfer water and materials—be it sediments, nutrients, or biota—from a disperse system to a increasingly concentrated system (Knighton, 1984). To the stream ecologist, lotic networks can follow a general pattern from the headwaters to the ocean. The most widely accepted account of this motif is the *river continuum concept* (Vannote et al., 1980). This approach is based on stream order, type of particulate organic matter present, nutrient concentrations, and type of aquatic insects present. The river continuum concept envisions that the coalescing network of streams in the drainage basin forms a continuum of physical gradients and associated biotic adjustments specific with ratios of the different types of aquatic insects present depending on whether the habitat is in a fast moving headwater stream (steep gradient) or a slow, lazy, meandering river (flat gradient), or whether the stream has more coarse particulate organic matter (leaves falling into the stream) than fine particulate organic matter. The concept also asserts that upstream concentrations of N and P are normally lower than downstream concentrations of N and P. In short, spatial autocorrelation is present and it may be due to the physical or structural nature of the stream network. Network analysis of structural or topographic characteristics such as contributing area, stream order, stream length, or drainage density of the fluvial network may explain the nutrient distributions within a watershed.

In a natural system, assuming the river continuum concept is correct, lower nutrient concentrations would be found in first order streams and higher nutrient concentrations would be found in higher order streams, which would result in positive autocorrelation. Therefore, nutrient concentration would be strongly related to stream order. In such a case, the residuals of a regression of nutrient concentration on stream order should not show any autocorrelation because the autocorrelation observed on nutrient concentration would be due to stream order. On the other hand, if the residuals of a regression of nutrient concentration on stream order still show autocorrelation, this is an indication that other factors other than stream order are affecting nutrient concentrations. Land managers and/or policy makers should account for this phenomenon in the development of their policies and land management strategies. For example, development of nutrient concentration criteria for ecoregions suggests that one set of nutrient criteria is expected to hold true across multiple order watersheds, which is not in agreement with the river continuum theory. Additionally, if certain physical features such as drainage density can explain the existence of autocorrelation, then a given portion of the watershed may be more or less vulnerable to nutrient loss. Consequently, determining the reasons for the existence of autocorrelation may be important in the development of policies (policy makers) and land management practices (land manager) to be used in a watershed.

The objectives of this work were to: (i) determine the system-wide spatial distribution of N and P concentrations in biweekly stream samples taken from two Southern Piedmont watersheds, and (ii) determine the relationship between N and P concentrations in biweekly stream samples and watershed morphological features in two representative watersheds of the Southern Piedmont.

MATERIALS AND METHODS

Watershed Description

Two fourth-order watersheds in Oconee and Greene counties (Greenbrier Creek and Rose Creek) were selected for this study because they are typical Southern Piedmont watersheds, where the presence of agriculture is prominent and urbanization is incumbent. In 1998, average percentages for land use categories agriculture, forest, residential, and miscellaneous were 27.5, 69.1, 0.1, and 3.1%, respectively, for these watersheds. This suggests a potential for nonpoint-source pollution from agriculture, which may be exacerbated by increased population density (Berndt et al., 1998). Both creeks are part of the Oconee River Basin, which flows into the Altamaha River. Uplands range from gently sloping to steep, and soils are predominantly well drained Kanhapludults, which tend to be highly eroded, weathered soils deplete of native nutrients. Old terraces from reclaimed cotton fields remain in forests and pastures and nonactive gullies tend to dissect forest land. Stream corridors are nearly level lowlands, which are subject to frequent flooding or are deeply incised channels. Lowlands are more prevalent further downstream but also occur near the headwaters.

The Southern Piedmont climate is temperate, humid, and rainfall is on average 1250 mm yr^{-1}. Precipitation totals are highest in the late winter and early spring due to the frequency of warm and cold fronts with a secondary maximum of precipitation in July due to thunderstorms fed from moist Atlantic winds (Hodler and Schretter, 1986).

Seventeen stream sampling sites were located on the Rose Creek and 18 stream sampling sites on the Greenbrier Creek (Fig. 1). Land uses represented by stream sites are: dairy, poultry–cattle, cattle, exotics [elk (*Cervus canadensis*) and red deer (*Cervus elaphus*)], row crops, hay, and forest. Sites were chosen to be disperse across the watershed but also to adequately analyze diverse land management practices on a particular tributary. Stream sampling sites are located upstream and downstream of various land management systems.

Biweekly Sampling

Biweekly sampling began in December 1998 and continued through December 2000. Samples were taken on a regular basis (every first and third Wednesday of each month) to reflect the true distribution of nutrient concentrations. This

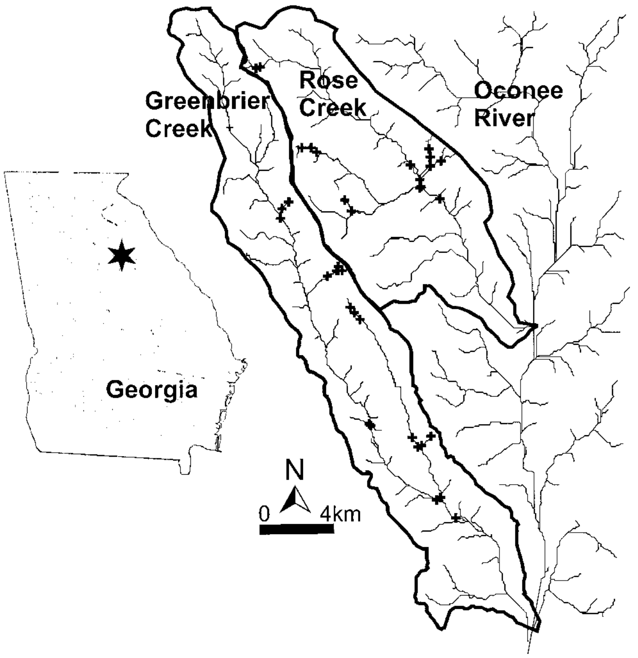

Fig. 1. Distribution of stream collection sites on the Greenbrier Creek and Rose Creek. Stream sample sites are depicted by plus sign. Location of watersheds in Georgia depicted by star.

sampling methodology ensured that the measure of central tendency and distribution was unbiased. Before each sampling, bottles were conditioned in-stream with "three bottle fills." Collected samples were filtered in the field through 0.45-μm CNA membranes, placed in dark iced coolers and transported to an analytical laboratory for analysis. Biweekly samples were analyzed for $(NO_3^- + NO_2^-)$–N, NH_4^+–N, and dissolved reactive P (DRP). All $(NO_3^- + NO_2^-)$–N was analyzed using the Griess-Ilosvay method (Keeney and Nelson, 1982), after reduction of NO_3^- to NO_2^- with a Cd column (Alpkem RFA method A303-S170, 0.02–1 mg N L^{-1}). The NH_4^+–N was determined by the salicylate–hypochlorite method (Crook and Simpson, 1971; Alpkem RFA method A303-S021, 0.01–0.5 mg N L^{-1}) and DRP was analyzed colorimetrically with the molybdate-blue method (Murphy and Riley, 1962; Alpkem RFA method A303-S203 with a 30-mm flowcell; 0.003–0.2 mg P L^{-1}). These colorimetric methods were implemented on an Alpkem RFA 300 autoanalyzer (Alpkem GCA, College Station, TX).

Network Analysis

Stream order and drainage density are quantitative measures of network composition and hierarchy and are the foundation for modern network analysis (Knighton, 1984). Contributing area and stream length are necessary to determine drainage density and may have influence on their own. We therefore analyzed both the Rose Creek and Greenbriar Creek for contributing area, stream length, stream order (Strahler, 1952), and drainage density upstream of each stream collection site. Absence or presence of riparian buffers was determined with site visits. If land adjacent to streams was vegetated with trees, shrubs, or grasses, no nutrients were applied, and was at least 3 m wide, then a riparian buffer was considered to be present.

Four, 7.5-min Topographic Quadrangles were obtained from the USGS, scanned into ERDAS Imagine (ERDAS, Atlanta, GA), rectified, registered, and joined. Watershed boundaries and streams were digitized from the computer screen at high resolution. Watershed scale network analysis was done using geographic information systems with available digital data. Four, 7.5-min DEMs (30-m ground resolution) were obtained from the U.S. Geological Survey (USGS) and imported into ERDAS Imagine, registered, and joined. The joined DEM was imported into ESRI Arc/Info (ESRI, Redlands, CA), cleaned, and imported into ESRI ArcView where it was analyzed for subwatershed boundaries with the Center for Research in Water Resources [CRWR, Univ. of Texas, www.ce.utexas.edu/prof/olivera/prepro/prepro.htm (verified 23 July 2002)] Preprocessor linked with ESRI ArcView. Stream order was determined using delineated streams with ground verification. Upstream values for stream length were obtained with the measurement tool in ArcView Spatial Analyst. Drainage density was calculated as stream length divided by contributing area.

Statistical Analysis

There are several potentially useful spatial analysis techniques that may be linked with GIS. These techniques may be separated out as either spatial analysis techniques or deterministic spatial techniques (Elston and Buckland, 1993; Fotheringham and Rogerson, 1994). In this work we used statistical methods that address the inherent stochastic nature of patterns and relationships, rather than the latter, which would have one outcome and may not take into account the possible random or spatial nature of environmental relationships. Of the stochastic methods, we used techniques concerned with exploring spatial autocorrelation and covariance structure. These techniques explore whether and in what way adjacent or neighboring values tend to move together both for the univariate and multivariate cases. In the univariate case (i.e., system-wide variation of P concentration), Moran's Coefficient (MC) or Geary's Coefficient (GC) are the most basic and commonly used methods (Goodchild, 1986; Griffith, 1987; Griffith, 1993). In the multivariate case (i.e., spatial distribution of nutrient concentrations in streams relative to watershed morphological features), multivariate correlation assesses the relationship between two measurements on a global level and can be accomplished through spatial regression or autoregression (Cliff and Ord, 1980; Cressie, 1991; Griffith, 1993). System-wide spatial distributions of ammonium-N, nitrate-N, and dissolved reactive phosphorus-P concentrations in biweekly surface water samples were analyzed for spatial autocorrelation using Moran's Coefficient (Goodchild, 1986; Griffith, 1987; Griffith, 1993). Values for Moran's Coefficient (MC) and corresponding illustrations for a variety of spatial distributions for area attributes and for network attributes (Fig. 2) indicate spatial clustering of similar objects (positive correlation; MC = 1), random objects (no correlation; MC = 0), and dissimilar objects (negative correlation; MC = −1). Calculations of MC were done using first nearest neighbor methods in SAS (SAS Inst., 1994; Griffith, 1993), which requires a connectivity matrix indicating the spatial relationship between the sampling sites and their corresponding contributing areas. Two different connectivity matrices were used. One connectivity matrix, *contributing area matrix* (the standard approach), was based on contiguity of contributing areas. Because the contributing area matrix did not account for the predominantly unidirectional nature of streams, a second connectivity matrix, *upstream matrix*, was developed based on upstream position. For example, a $n \times n$ connectivity matrix "N" was built with n rows and n columns, where n is the number of sampling sites. In the contributing area matrix, if Site 1 is contiguous to Site 2, then $N_{12} = N_{21} = 1$. Sites that are not

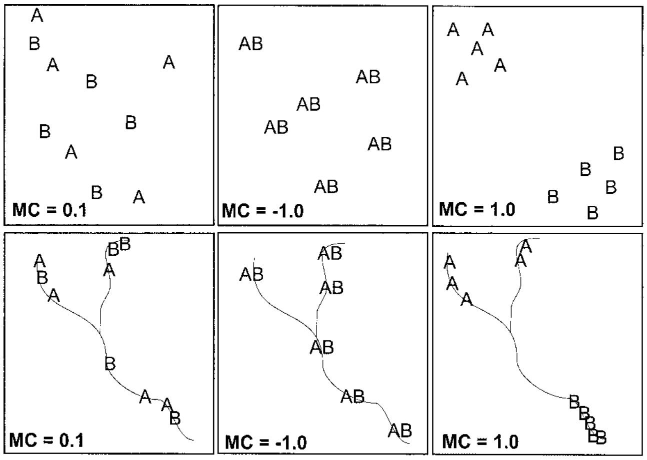

Fig. 2. Diagram of spatial distribution of A and B as area (*upper boxes*) and network (*lower boxes*) attributes. Spatial distributions of attributes are described with spatial autocorrelation analysis technique Moran's Coefficient (MC). When like attributes are clustered together, MC = 1; unlike attributes clustered, MC = −1; and random location, MC = 0.

contiguous have a zero in their corresponding matrix position. In the upstream matrix, if Site 1 is upstream of Site 2, then $N_{12} = 1$, but $N_{21} = 0$ (because Site 2 is not upstream of Site 1).

Contributing area and upstream matrices were developed for each date of collection. Because of the 1999 and 2000 droughts and because we started collecting before all stream sites were in place, the number ($n \times n$ matrix) ranged from 12 to 18 on the Greenbrier Creek and from 8 to 17 on the Rose Creek. Averages of Moran's C of all collection dates by chemical species were calculated for the contributing area matrix and for the upstream matrix. Autoregressions were run when autocorrelation was significant ($p > 0.10$) (Griffith, 1993). Autoregressions with coefficients of drainage density and stream order, and autoregressions with coefficients of contributing area and stream length were run for biweekly sample nutrient concentrations. Residuals were analyzed for spatial autocorrelation to determine if any of the coefficients explained the spatial autocorrelation present.

Univariate analysis (SAS Inst., 1994) was executed to summarize descriptive statistics and to determine likelihood of a normal distribution for biweekly sample data. Rank transformation/ANOVA (Kruskal-Wallis test) was used in this study to explore differences in biweekly sample nutrient concentrations between watersheds as well as between presence and absence of riparian buffers. When data within groups (treatments) are not normally distributed or when they do not have equal variances, nonparametric methods of analysis are advised (Helsel and Hirsch, 1992; Conover, 1980).

RESULTS AND DISCUSSION

General Results

Analysis of the data showed that kurtosis was well above one and the distributions were not normal (data not shown). Therefore, nonparametric analyses were carried out as described before for central tendency (median is therefore a better indicator of central tendencies) and for differences between groups. Pooled system-wide concentrations of ammonium ranged from <0.01 to 2.10 mg N L^{-1} with median concentrations ranging from 0.07 to 0.11 mg N L^{-1} (Table 1). There was no significant difference between Rose Creek and Greenbrier Creek in median ammonium concentrations. However, median stream nitrate concentrations were significantly higher in the Rose Creek than in the Greenbrier Creek in 1999 and 2000 (Table 1). In contrast, median stream DRP concentrations were significantly lower in the Rose Creek than in the Greenbrier Creek, also for both years (Table 1). Additionally, nitrate and DRP median concentrations decreased significantly from 1999 to 2000 in both watersheds ($p < |t| = 0.01$).

Table 1. Drainage area, drainage density, and median nutrient concentrations for Greenbrier Creek and Rose Creek.

Year	Greenbrier	Rose	$p > [t]$†	Pooled data
	mg NH_4–N L^{-1}			
1999	0.07	0.07	0.99	0.07
2000	0.11	0.11	0.34	0.11
	mg NO_3–N L^{-1}			
1999	0.51	0.83	0.0001	0.62
2000	0.47	0.60	0.0001	0.52
	mg DRP L^{-1}			
1999	0.023	0.014	0.0001	0.017
2000	0.013	0.007	0.0001	0.010
Watershed morphology				
Area, km^2	61.8	78.9		
Drainage density, km km^{-2}	1.0	2.2		

† Probability for comparison of ranked stream nutrient concentrations between Greenbrier Creek and Rose Creek according to Fisher's LSD.

Although this was not a study focusing on the efficacy of riparian buffers the presence or absence of buffers could have had an impact on stream nutrient concentrations. Analysis of variance (Rank/Transformation) indicated the presence of riparian buffers was associated with increased nitrate concentration in the Greenbrier Creek, but was not related to nitrate concentration in the Rose Creek.

Autocorrelation and ANOVA Results

Spatial distribution of nutrients concentrations was calculated for each watershed on a sampling date by sampling date (case by case) basis using Moran's Coefficient (MC) with connectivity matrices for contributing area and upstream position. The MC values are presented for each watershed with contributing area matrix and upstream matrix by nutrient (Fig. 3, 4, 5, 6, 7, and 8). An absolute value of 0.25 or greater for Moran's coefficient indicates autocorrelation is present (Goodchild, 1986).

Ammonium

There were no significant cases of spatial autocorrelation for ammonium on the Greenbrier Creek watershed for either connectivity matrix in 1999. Average Moran's Coefficient (MC) across cases was −0.04 (MCca) for the contributing area matrix and −0.04 (MCup) for the upstream matrix. Only 4 out of 22 (4/22) cases indicated some spatial autocorrelation on the Rose Creek, three

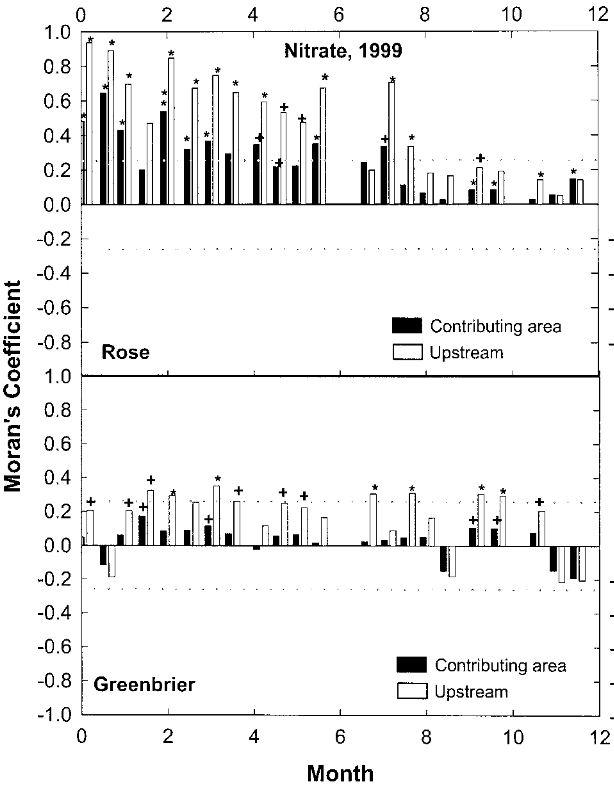

Fig. 3. Spatial autocorrelation for nitrate in Rose Creek (*upper*) and Greenbrier Creek (*lower*) for 1999. (Symbols *, **, + used to show 5, 1, and 10% levels of significance, respectively).

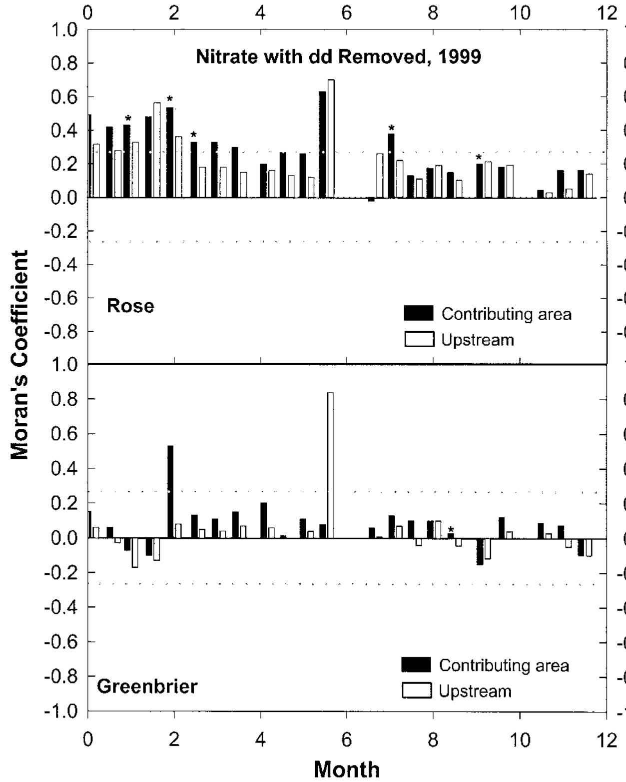

Fig. 4. Spatial autocorrelation for nitrate on residuals for autoregression on drainage density (dd) in Rose Creek (*upper*) and Greenbrier Creek (*lower*) for 1999. (Symbols *, **, + used to show 5, 1, and 10% levels of significance, respectively).

of which were identified with the contributing area matrix. Average Moran's C across cases for contributing area and upstream were −0.04 (MCca) and −0.05 (MCup), respectively. A negative MC indicates there is a clustering of dissimilar objects, suggesting that ammonium concentrations when close together in space tended to be dissimilar. Within both watersheds, where multiple land management systems and fertilization sources exist essentially side by side, a negative MC would be expected.

Nitrate

On the Greenbrier Creek watershed, in Year 1999, 13 out of 22 cases, nitrate concentrations for biweekly samples were significantly spatially autocorrelated at the $p < 0.10$ level, when considering the upstream matrix (Fig. 3). Only 3 out of 22 cases were significantly spatially autocorrelated when considering the contiguity of contributing area. The average Moran's C across cases for contributing area and upstream matrices was 0.04MCca and 0.29MCup, respectively. In Year 2000, weak autocorrelation was evident in the wetter months of the year and was essentially absent for the later months, which were drier (Fig. 5). Because rainfall during or just before collection could influence nutrient concentrations in streams, rainfall events for the two watersheds was checked to determine if this influence was possible. No runoff-producing rainfall events (runoff collection devices are located in fields that would contribute to stream collectors) occurred in 2000 within 2 d of biweekly samplings.

Autoregression using drainage density, stream order, stream length, and contributing area (network factors) as independent variables was carried out to determine if the spatial autocorrelation was a function of the inherent physical nature of the watershed. In only one case did contributing area significantly explain the spatial autocorrelation. Stream order and stream length were always insignificant. However, in 10 out of 12 cases of spatial autocorrelation, drainage density significantly reduced the spatial autocorrelation of nitrate on the Greenbrier Creek in Year 1999 (Fig. 4) to 0.05 MCup (avg. MCup across the 10 cases without autoregression was 0.29).

On the Rose Creek watershed 15 out of 22 cases were significantly spatially autocorrelated (avg. MCca = 0.25 and avg. MCup = 0.48) for Year 1999. Autoregression with drainage density reduced spatial autocorrelation in 13 out of 15 cases (Fig. 4). However, in 6 of the 13 cases p was between 0.10 and 0.15. Little autocorrelation was evident in Year 2000 for either measure of connectivity.

Drainage density decreased spatial autocorrelation in both watersheds when autocorrelation was present. Large drainage densities indicate highly dissected watersheds and highly dissected watersheds tend to move water more efficiently or quickly (Knighton, 1984). This rapid movement may prevent or impede nitrate removal mechanisms within the watershed and particularly within riparian buffer zones. The mechanisms that may be hampered are denitrification, assimilation, and reten-

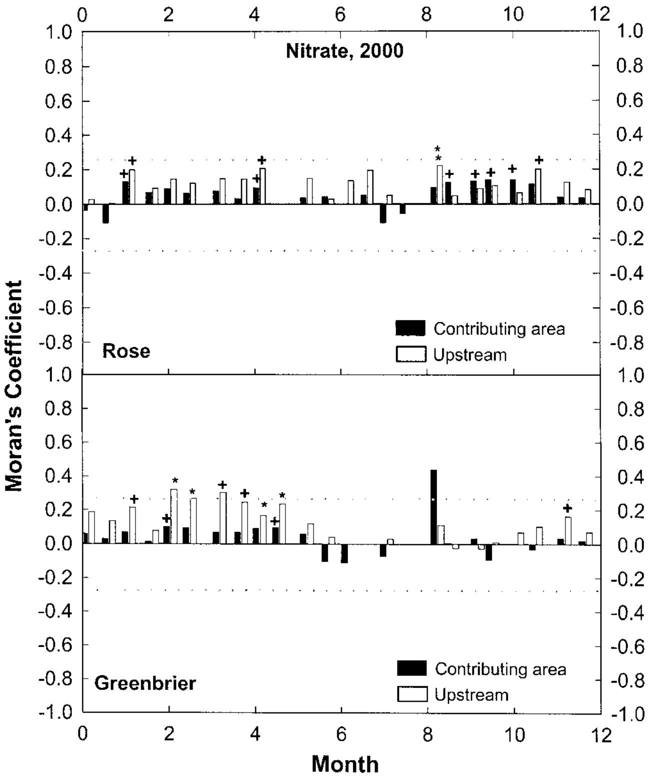

Fig. 5. Spatial autocorrelation for nitrate in Rose Creek (*upper*) and Greenbrier Creek (*lower*) for 2000. (Symbols *, **, + used to show 5, 1, and 10% levels of significance, respectively).

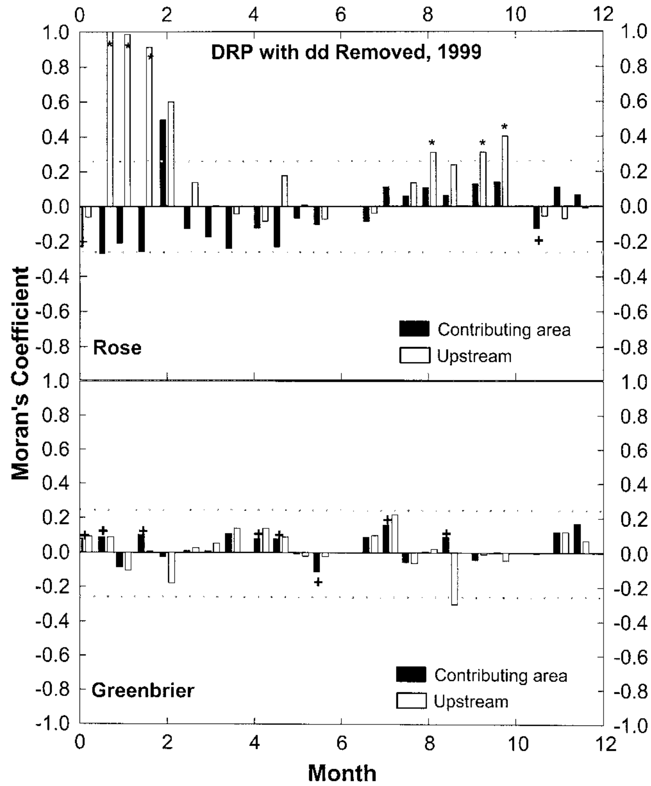

Fig. 7. Spatial autocorrelation for DRP on residuals for autoregression on drainage density (dd) in Rose Creek (*upper*) and Greenbrier Creek (*lower*) for 1999. (Symbols *, **, + used to show 5, 1, and 10% levels of significance, respectively).

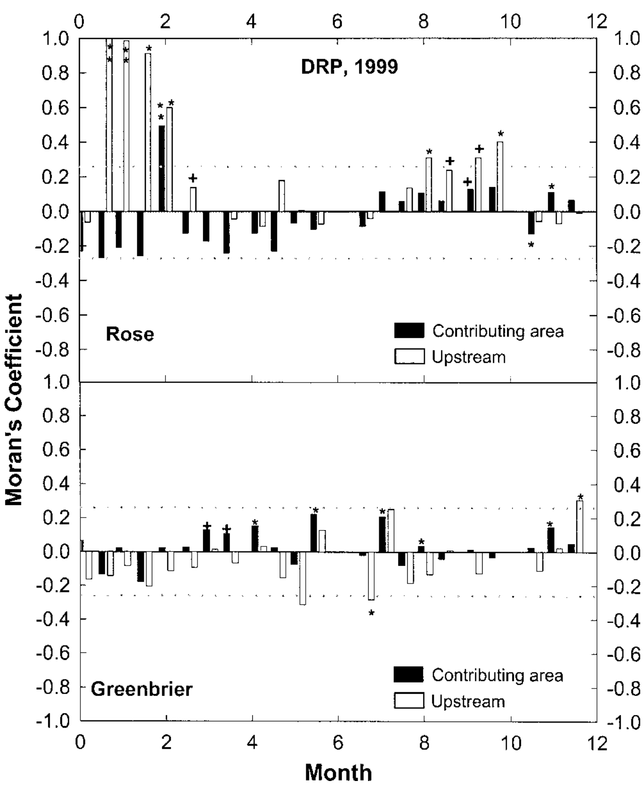

Fig. 6. Spatial autocorrelation for DRP in Rose Creek (*upper*) and Greenbrier Creek (*lower*) for 1999. (Symbols *, **, + used to show 5, 1, and 10% levels of significance, respectively).

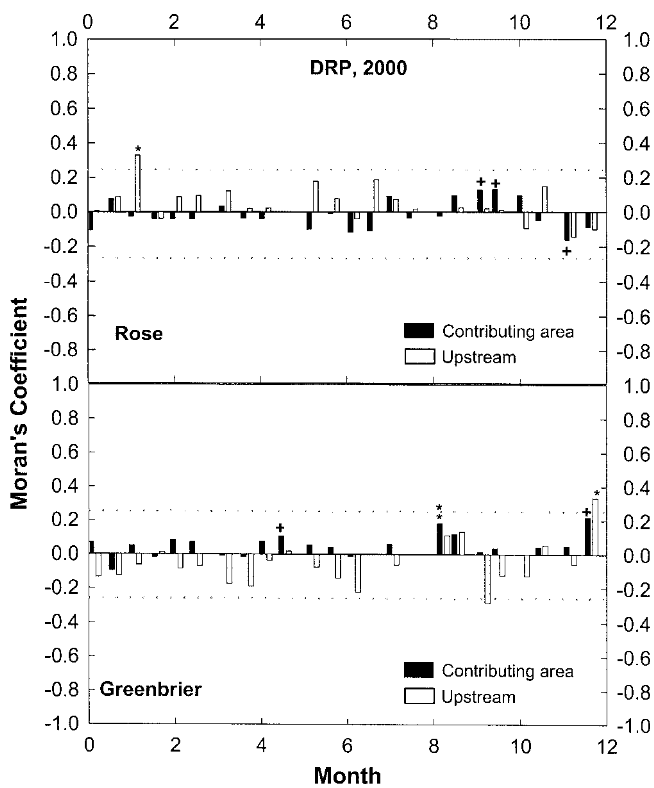

Fig. 8. Spatial autocorrelation for DRP in Rose Creek (*upper*) and Greenbrier Creek (*lower*) for 2000. (Symbols *, **, + used to show 5, 1, and 10% levels of significance, respectively).

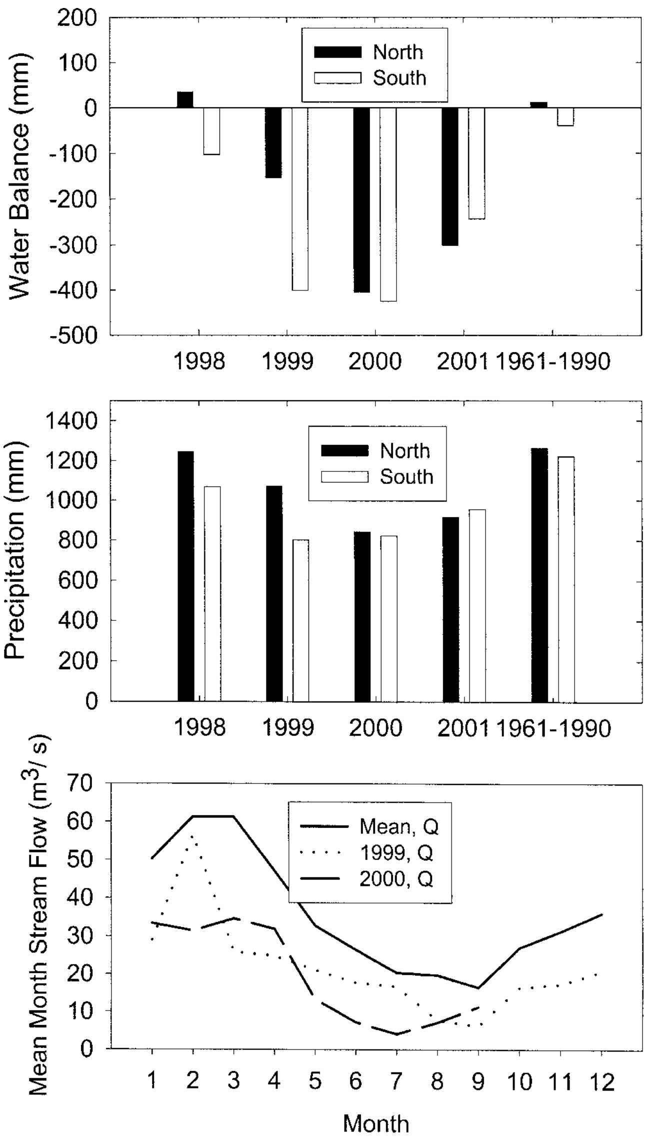

Fig. 9. Water balance and precipitation north and south of the watersheds, and discharge of the Oconee River at a point downstream of the confluence of Rose Creek and Greenbrier Creek with the Oconee River (USGS, Penfield, GA).

tion by vegetation, as well as transformations of nitrate to ammonium or organic N.

Of additional interest is the lack of autocorrelation in Year 2000. Weather stations on the north (30°88′ N lat, 83°42′ W long) and south (33°38′ S lat, 83°48′ W long) ends of the watersheds (Fig. 9) indicated that rainfall was at least 150 mm below average in 1999 and at least 300 mm below normal in 2000. Water balances for the north of the watershed indicated that the deficits were about two times greater in 2000 than in 1999. Mean monthly stream flow for a station located on the Oconee River just below the confluence of the Rose and Greenbrier Creeks (USGS, Penfield, Greene County, GA) indicated that flows were well below average flows for both 1999 and 2000. Battaglin and Goolsby (1997) found that nitrate concentrations in midwestern rivers were correlated with soil porosity and suggested that elevated nitrate concentrations in stream may not be directly tied to increased overland flow but rather associated with increased shallow subsurface flow. Our drought conditions could have resulted in diminished shallow subsurface flow and leaching. In a long-term midwestern stream study, years with lower than usual precipitation were found to have lower than usual stream nitrate concentrations, which were attributed to lack of leaching in the vadose zone (Jaynes et al., 1999). In this study, nitrate concentrations were also found to be lower in both watersheds in Year 2000. In a study by Morecroft et al. (2000) to evaluate the effect of drought on nitrate leaching and stream nitrate concentrations, nitrate concentrations in streams were lowest during drought conditions and the lowest concentrations for the years occurred when subsurface flow was at its lowest. Battaglin and Goolsby (1997) also found that contributing area affected nitrate concentrations in streams, while the results of this study showed that contributing area did not explain the autocorrelation found for nitrate.

Dissolved Reactive Phosphorus

Spatial autocorrelation for DRP was essentially absent on the Greenbrier Creek (Fig. 6; MCca = 0.03 and MCup = −0.06) as well as on the Rose Creek for contiguity of contributing area (MCca = −0.05). When considering the upstream position measure of connectivity for the Rose Creek, however, spatial autocorrelation appeared to be somewhat present (avg. MCup = 0.24) across all cases but only significant in 8 out of 22 cases. In those cases that were significant, MCup averaged 0.65. This is to say that on 8 of the 22 sampling days there was significant spatial autocorrelation. Autoregression of inherent physical factors of the stream network did not significantly reduce spatial autocorrelation for DRP where there was significant spatial autocorrelation (Fig. 7). This suggests that something other than stream order, stream length, contributing area, and drainage density is influencing the spatial distribution of DRP biweekly sample concentrations in the Rose Creek. In Year 2000, only one case of significant spatial autocorrelation was identified for the Rose Creek and the Greenbrier Creek watersheds (Fig. 8).

SUMMARY AND CONCLUSIONS

Our working hypothesis was that inorganic N and DRP concentrations in streams draining two watersheds were likely to vary because of innate morphological features of the watersheds in addition to land management aspects. The morphological features taken into account were stream order, drainage density, contributing area, and stream length. Stream order would be expected to influence nutrient concentrations according to the river continuum concept in which concentrations increase with stream order.

We did not find spatial autocorrelation for ammonium in any of the watersheds. Spatial autocorrelation for DRP was low in the Greenbrier Creek watershed, but was very prominent in the more dissected Rose Creek watershed. Yet, none of the morphological features considered explained the DRP autocorrelation observed. We found a positive spatial autocorrelation for nitrate in both watersheds, although it was stronger in the Rose Creek watershed. Drainage density explained a significant portion of this autocorrelation for nitrate.

The presence of spatial autocorrelation for nitrate and its explanation by drainage density suggests that nitrate concentration in streams can be related to morphological features. This is not to say that management does not have an impact on nutrient concentrations in streams but rather that the degree to which management has an effect on nutrient concentrations is modified by the physical features of the watershed and that these features should be considered in the development of land management plans, watershed risk assessments, watershed nutrient criteria, or risk assessment tools.

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